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PART 1

INTERACTIVE COMPOSITE JOINT DESIGN

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Final Report for Period April 1976 to April 1978

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This technical report has been reviewed and is approved for publication.

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A computing technique was developed to determine the feasibility of combining the several batch computer programs for the analysis of composite joints into one interactive computer program utilizing graphics display. This approach proved successful and produced a design tool for the analysis of bolted or bonded composite joints. The program utilizes the software package provided by TEKTRONIX for the graphics display. The user works at the remote on-line graphics terminal in conjunction with the main computing facilities which contain the program.

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The final report discusses the summary, conclusion, and recommendations of the work performed. The User's Manual and Programming Manual discusses the input, output, and function of the program

FOREWORD

This report is one of a series that described work performed by Douglas Aircraft Company, McDonnell Douglas Corporation, 3855 Lakewood Boulevard, Long Beach, California 90846, under the Interactive Composite Joint Design Program. This work was sponsored by the U. S. Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, under contract F33615-76-C-3058.

This report is divided into three parts. Part 1 is entitled "Final Technical Report", part 2 is entitled "User's Manual", and part 3 is entitled "Programming Manual". The principle investigators and authors are M. K. Smith, C. G. Dietz and L. J. Hart-Smith.

Mr. James R. Johnson was the Air Force Project Engineer during the conceptual phase of this project. During conduct of the program, Mr. Johnson was succeeded by Lt. K. Schrader (AFFDL/FBRA).

This report was submitted to the Air Force on 15 April 1978, and covers work performed during the period April 1976 through April 1978.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION I

INTRODUCTION

This is the final technical report for the Interactive Composite Joint Design Program, and covers the development of the resulting JOINT Computer Program. The User's Manual and Programming Manual are contained in parts 2 and 3, respectively of this report.

OBJECTIVE

The basic objective of this effort was to develop a computer-aided analysis capability for the non-specialist to design and analyze different types of bolted and bonded composite structural joints. This effort was to utilize the capabilities of interactive graphics as the interface between the user and the analytical procedures.

TASKS

Work on the development of the JOINT Program covered the period from April 1976 through April 1978, and included the following four tasks.

Tasks I and II were to develop techniques for the analysis of bonded and bolted composite joints, respectively, and a set of interactive joint design techniques for analyzing several classes of joints. These joint classes included the double-lap, supported and unsupported single-lap, tapered double-lap, scarfed, and stepped-lap configurations.

Task III was to develop a calculation technique combining the techniques and methods developed in Tasks I and II above, which would permit the designer to make a selection of joining methods, materials and detailed joint configurations.

Task IV was to develop sample designs using the techniques for each class of joint considered, and make recommendations for future development beyond the pilot techniques.

BATCH ANALYSIS

At the start of the program, the state of the bolted joint methods consisted of conventional deferred processing (batch) of balanced double-lap joint designs.

The analysis of bonded joints had been advanced by some previous development contracts. The double-lap batch program determined the allowable load in the form of non-dimensioned parametric output. The unsupported single-lap analysis was coded for parametric output of different adherend thicknesses and overlaps, with a separate program for stiffness imbalances.

For the scarf joint, three different batch programs determined the allowable joint load of a design for elastic, elastic-plastic, and special elastic-plastic solutions. The allowable load for a stepped-lap joint was accomplished by two batch programs for elastic and elastic-plastic solutions.

RESULTS

The final product is a FORTRAN computer program that utilizes the graphics routines contained in the Tektronix PLOT10 software library. It provides the user with the advantages of execution on an on-line graphics terminal, while avoiding the restrictions of cost, size, and software imposed by the more sophisticated buffer-type terminals.

Program development was accomplished on the ASD (Aeronautical Systems Division) CDC computer installation at Wright-Patterson Air Force Base. Execution for checkout utilized a Tektronix 4014 graphics terminal. The resulting program provides the following advantages:

- easy access to the analytical methods
- on-line execution
- nearly instant visibility of output
- convenient editing features
- relatively low cost

- eliminates the use of card input
- allows modification and re-analysis
- adaptable to different computer installations
- provides re-start capability.

SECTION II

DEVELOPMENT

Development of the JOINT program was essentially divided into the graphics development and the analytical development.

Since batch programs existed in some form, Dr. Hart-Smith and Mr. Dietz developed further batch capabilities on the Douglas IBM computers. These programs were then integrated into the Wright-Patterson CDC JOINT program by replacing the input and output sections.

GRAPHICS HARDWARE

The choice of the Tektronix graphics terminal was based on its availability, lower operating cost, lower terminal acquisition cost, universal software accessibility, and program considerations based on the pilot technique to be developed.

The on-line graphics hardware considered consisted of the IBM 2250 display terminal, the CDC 274 display terminal and the Tektronix 4014/4015. The first two types are buffer or refresh-type light-pen-capability terminals, but the software packages for implementation are for exclusive use with IBM and CDC computer installations, respectively. The Tektronix 4014/4015 type terminals are non-refresh screens whose PLOT10 software package is available to both the IBM installation at Douglas Aircraft Company, and the ASD CDC installation at Wright-Patterson Air Force Base.

ACCOMPLISHMENTS

Data Communication

The reader/printer terminal at Douglas was the main data communications link with Wright-Patterson. Through this terminal update decks were loaded and all jobs printed. Batch submittal was used to update files and obtain a new executable data set. This absolute file, called JOINT, was accessed and executed by using a Tektronix terminal and a dial-up data phone with a 300 BAUD line.

Initially, an attempt was made to use the Douglas IBM computer installation to develop the technique and maintain a parallel program on the ASD CDC computers at Wright-Patterson Air Force Base. Three situations forced the decision to complete development on the CDC at Wright-Patterson: First, the development and maintenance of two separate programs was inefficient; second, the long-term conversion of the Douglas IBM facility to MVS (Multiple Virtual Storage) seriously disrupted reliability; third, the NOS/BE system of CDC under which this program was to run was more critical than the IBM.

Program Functions

The primary function of the JOINT program was to provide capability for the analysis of composite joints.

Second, a data file was provided the user for obtaining permanent hard copy printout of the problems analyzed. This PRINT file capability was later extended to permit the re-printing of solutions at a subsequent JOINT session.

Third, a SAVE file was provided for the unformatted storage of solution input and output data, to provide a permanent storage medium, to use as input to a new analysis, and to obtain formatted output for the PRINT file or screen viewing.

Therefore figure 1 shows the main program options available to the user.

The selection of option 1 will clear the screen and display figure 2 for the selection of the joint type. Figures 3 and 4 are displays for the input and output of an analysis, and some of the options available to the user.

The user labels each analysis by supplying an analysis name, up to eight characters long. The program never checks a name for duplication. If the solution is saved, it is tracked internally by a sequential design number, thereby allowing the designer more flexibility.

Editing Input Data

Due to the number of input constraints required for the analysis of the bonded joints, an editing feature allows the user to select and modify any constraint by selecting its associated box. Figure 3 shows how the display looks for the example shown. This feature is especially useful when changing parameters displayed from a previous analysis, as well as making corrections.

```
                    COMPOSITE JOINT DESIGN PROGRAM

          ---->     CODE    OPTION
                      1 =   ANALYZE JOINT
                      2 =   SELECTIVE OUTPUT OF SOLUTIONS FROM SAVE FILE
                      3 =   CONSOLIDATE SOLUTIONS ON SAVE FILE
                      4 =   EXIT
ENTER CODE: 1
```

Figure 1. Main Joint Program Menu

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```
                  ANALYSIS OPTIONS

                            JOINT CODE
      CLASS                BOLT    BOND

 STANDARD DOUBLE-LAP        1       5
 UNSUPPORTED SINGLE-LAP     2       6
 SUPPORTED SINGLE-LAP       3       7
 STEPPED-LAP                4       8
 SCARFED                            9

ENTER NUMERIC CODE (0 = RETURN): 5

INPUT DATA FROM A SOLUTION ON SAVE FILE? (1=YES, 0=NO): 0
```

Figure 2. Analysis Options

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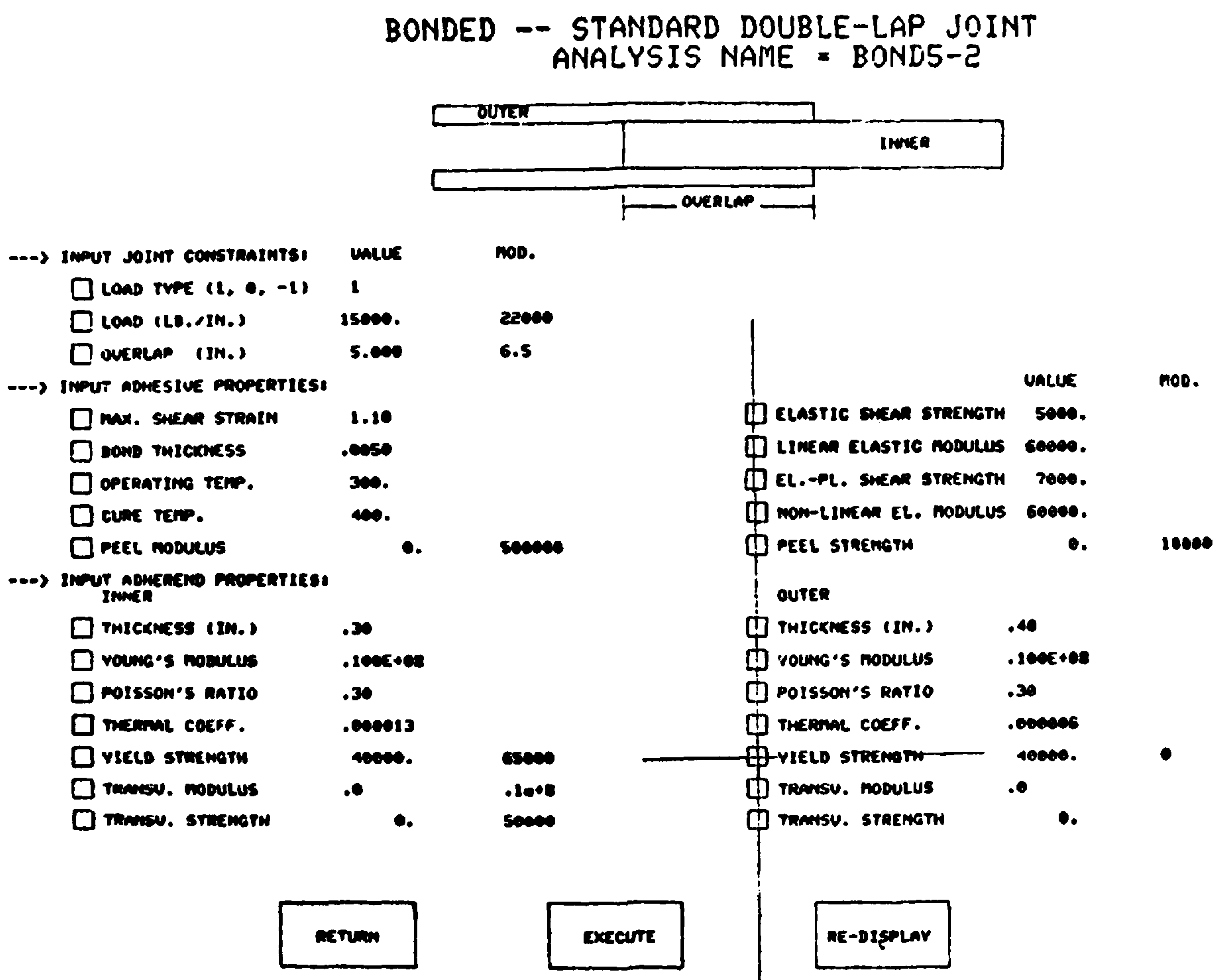

Figure 3. Typical Analysis Input Display

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```
                    BONDED -- STANDARD DOUBLE-LAP JOINT
                       ANALYSIS NAME - BONDS-2

BASIC DATA:  LOAD TYPE      -  1 (TENSION)
             LOAD (LB/IN) - 22000.
             OVERLAP (IN) -  6.500

ADHESIVE PROPERTIES:
          MAX. SHEAR STRAIN           1.10         ELASTIC SHEAR STRENGTH (PSI)    5000.
          BOND THICKNESS      (IN.)   .005         LINEAR ELASTIC MODULUS (PSI)   60000.
          OPERATING TEMP.     (F.)    300.         EL.-PL. SHEAR STRENGTH (PSI)    7000.
          CURE TEMP.          (F.)    400.         NON-LINEAR EL. MODULUS (PSI)   60000.
          PEEL MODULUS        (PSI)   500000.      PEEL STRENGTH          (PSI)   10000.

ADHEREND PROPERTIES:                  (INNER)      (OUTER)
          THICKNESS           (IN.)   .30          .40
          YOUNG'S MODULUS     (PSI)   .100E+08     .100E+08
          POISSON'S RATIO             .30          .30
          THERMAL COEFF.              .0000130     .0000060
          YIELD STRENGTH      (PSI)   65000.       65000.
          TRANSV. MODULUS     (PSI)   .100E+08     .100E+08
          TRANSV. STRENGTH    (PSI)   50000.       50000.

JOINT ANALYSIS:
          OPTIMUM OVERLAP (IN.) -  3.20

          ADHESIVE SHEAR TYPE-     STRENGTH(LB/IN)  STRAIN
             ELASTIC-PLASTIC            26627.
             LINEAR ELASTIC              5455.       .083
             NON-LINEAR ELASTIC          7904.       .117
             PLASTIC                                 .983

          ADHERENDS-  INNER             19500.
                      OUTER             52000.

          LIMIT DUE TO
          ADHESIVE PEEL OR
          INTERLAMINAR TENSION-         21816.

STRENGTH COMPUTATION
  OVERLAP (IN.) 6.50          BOND SHEAR STRENGTH (LB./IN.) 26627.
  BOND MORE CRITICAL WHERE INNER ADHEREND EXTENDS FROM JOINT

JOINT STRENGTH LESS THAN APPLIED LOAD

*  OUTPUT TO PRINT FILE *   OUTPUT TO SAVE FILE   *  RE-ANALYZE  *  RETURN  *
```

Figure 4. Output Display

SECTION III

SUMMARY

The resulting JOINT program allows the user to perform analytical computations on several types of composite joints, bolted or bonded, using a variety of materials and attachment methods.

To enhance this capability the user is provided with optional disk data files for the saving and/or printing of resulting solutions. If the user saves a solution, the input data may be used as basic data to a new problem, to be modified and re-analyzed at a later time. This reduces the time and effort required to analyze a joint type with input constraints similar to all those of a previous analysis. This SAVE file may also be used to view or output to the print file any of the solutions it contains.

The on-line execution of this technique provides for easy access, fast execution of multiple composite joint designs, instant visibility of results, and convenient methods of editing, modifying, and re-execution.

All this is provided through a Tektronix graphics display terminal that is easily adaptable to most computer installations.

SECTION IV

CONCLUSIONS

In April 1977 an extension to the contract advanced the development program from a pilot technique to a design tool. This changed the primary emphasis from the graphics technology development to the analytical methods development.

The analysis of composite joints is based on numerical methods and numerical output. The designer inputs numerical constraints and evaluates the design by its weight, margins of safety, comparison with allowables, failure modes, etc. The geometric assessment of a design is accomplished by reviewing values for overlap length, thicknesses, spacing, etc., rather than a visual representation of these values.

The major objective of a computer program is to find the best possible method to aid the user in analyzing a problem. The designer usually has two options: (1) batch submittals utilizing input data on punched cards, and (2) on-line computing where data is entered via the keyboard. On-line (interactive) computing gives the user nearly instantaneous execution of commands due to the inherent higher, and thus more costly, priority. Therefore, batch execution of a given set of problems, compared to on-line execution, usually has a lower computer cost and about the same or lower number of man-hours. If the user must solve a problem by iteration, the on-line approach has obvious advantages. The "man-in-the-loop" approach reduces the elapsed time for completing several iterations of a problem, based on the results of previous executions.

The use of graphics for an on-line program adds several dimensions to the program development specifications. First, the use of graphics must be beneficial to the user. Any on-line program can be integrated into a graphics approach, but the final product must make use of the graphics capability to provide significant overall advantages to the user. This could include dimensioned pictorials or schematics, curve plots, and graphis for analytical

work. Secondly, the software packages necessary use computer core that may be better used in program development. Thirdly, the user is tied to a specific type of terminal, and in many cases to a specific type of computer, due to the program calls to the software to operate the terminal. Conversion from one to another is possible, but the resulting program may be unsatisfactory.

The more sophisticated the on-line operation, the more costly the operation, the more sophisticated the software language, and the more restricted the user is to the terminal type on which theprogram will execute. To use non-graphics programs, any on-line terminal may be used that does not require special routines to operate. This includes most typewriter terminals, including portables, as well as display terminals, including the Tektronix 4014 and 4015.

For this particular application program, the designer is interested in the numerical values. No beneficial use could be found for displaying the data graphically (curve plots or tables). The addition of routines that would graphically represent the joint was determined to be a marginal trade-off, as the increase in program size was prohibitive. Secondly, over 10% of the executable program consists of Tektronix library routines (30% for system routines); this core space is more critical as the total size allowed by the computer installation decreases. The overlay of routines also is very essential to permit the program to be loaded.

Therefore, the three main modes of program execution are deferred processing (batch), an on-line typewriter, and on-line graphics. Below is a brief comparison of on-line graphics capabilities with deferred processing.

GRAPHICS	BATCH
Remote access	Lower computing cost
Iteration capability	Multiple designs
Editing	All problems printed
Fast solution visibility	
No card decks	

To compare on-line graphics to an on-line typewriter, the following list has been compiled.

GRAPHICS	TYPEWRITER
Screen display (printer optional)	Permanent hard copy
Potentially higher line speeds	More portable
Drawing capability	Software independent
I/O positioning possible	Line-by-line printing

Each of the above has its advantages and disadvantages; however for this particular application, the user has an interactive graphics program that takes full advantage of the capabilities provided on-line graphics.

Much has been learned from this contract, as there was no precedent for the interfacing of analytical programs with a graphics that could be found. The ability to display and edit the many input variables in the bonded joints proved to be very significant. Also, the use of the crosshairs for screen selection allowed visibility of the selections while avoiding the display of additional data. Keeping the screen clean was also a prime consideration during development, to avoid confusing data and allow clear copies of the screen.

SECTION V

RECOMMENDATIONS

1. Currently, the only time that the user is notified of the amount of elapsed time for the session is when the analysis name is requested. It may be more beneficial if this notification appeared after the user selects EXECUTE, with the option to RETURN rather than risk exceeding the time limit during execution.

2. The production JOINT program is near the maximum field length for execution on INTERCOM. It is recommended that the program be converted from OVERLAY to a method that does not affect the code, and provides more sophistication. During this conversion, it is also recommended that the subroutine DESIGN be expanded to call the appropriate input, analysis, output, and post-processor routines. This would accomplish the following:

    1) reduce the program size

    2) make it more flexible for other systems

    3) clean up the code and make it easier to follow

    4) make it easier to overlay.

3. During development, the number of potential analyses was reduced from 11 to 9. The variable NC ranges from 1 to 11 to correspond to the original sequence. It is recommended that NC be set equal to the analysis code selected in DESIGN, which ranges from 1 to 9. This change would affect some comment statements as well as code that checks specific values of NC. Since the type is written to the SAVE file, old files would not be compatible to the updated program version.

4. The use of Cyber Control Language (CDC's version of catalogued procedures) may be used to prepare files for use by the JOINT program.

5. The SAVE file is used mainly for the storage of solutions. This capability can be expanded to include the saving of the input data after selection of EXECUTE by analyses that permit input from the SAVE file. If the program is aborted during EXECUTE, the input data is currently lost. The following modifications wouldprovide an intermediate save; after the EXECUTE has completed and the output displayed, the user may select SAVE to replace the intermediate data on the file. If no SAVE is requested, an end-of-data flag will eliminate the intermediate data on the file and restore it to its original status.

Program update procedure: After EXECUTE has been selected, but before the analysis routine has been entered, perform the following operations.

```
      WRITE(1) NDT, TMPNAM, NC
      WRITE(1) NENT, (WORK(I), I=1.NENT)
      IEND=999
      WRITE(1) IEND, TMPNAM, NC
      DØ num I=1,3
  num BACKSPACE 1
```

This procedure writes the data out and re-positions the file. To eliminate the data when no SAVE is selected, modify the end of the SELECT routine as follows.

```
  300 IF(IX.GT.605) GØ TØ 100
      IF(IX.GE.515) N=0
      IF(IS.EQ.1) GØ TØ 400
      IEND=999
      A = 1.
      WRITE(1) IEND, A, A, N
      BACKSPACE 1
  400 RETURN
      END
```


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